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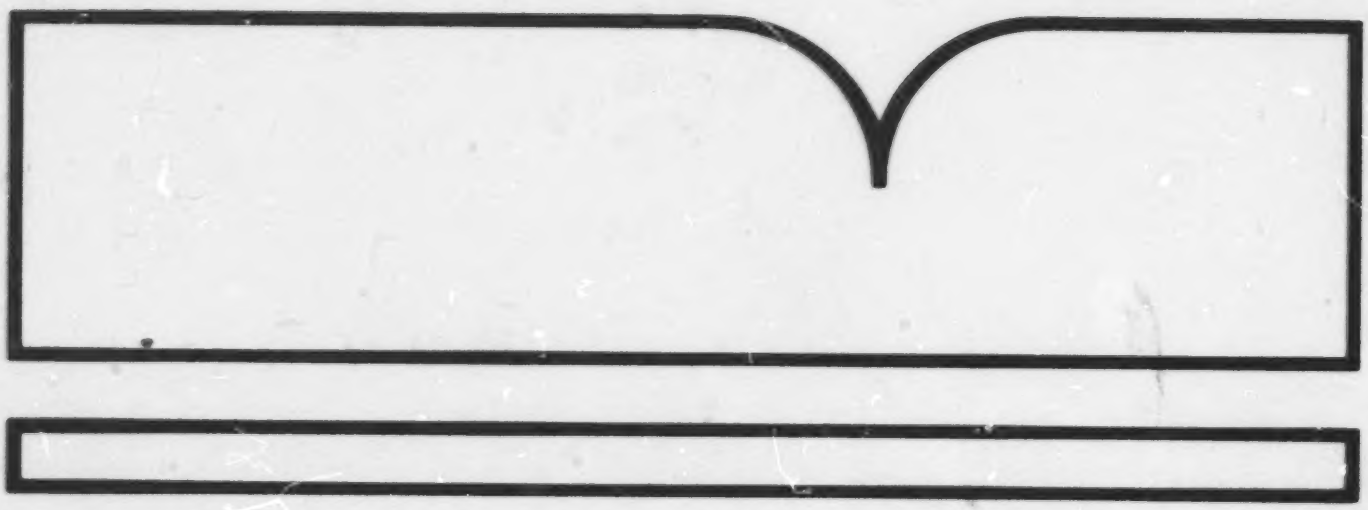

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16. ABSTRACT

Waste site ecological assessment is still in its formative stages. However, there appear to be no major obstacles preventing it from rapidly developing into a vigorous and useful science. There is no simple or single approach that will be generally applicable. Given the complexity of ecological systems, one must design each assessment carefully using the methods appropriate for the questions being asked.

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CAPABILITIES AND LIMITATIONS OF APPROACHES TO IN SITU ECOLOGICAL EVALUATION

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INTRODUCTION

This symposium presents a number of excellent papers on how to gather information on in situ biological conditions, especially at waste sites. Over the years biologists have had little difficulty gathering large amounts of information about our living environment. This is not surprising given the enormous variety and complexity of ecological systems; there are an almost endless number of features to be measured.

The problem comes in drawing useful ecological conclusions from the information we collect. More appropriately, how do we decide what information to collect in order to draw useful ecological conclusions? This point can be illustrated by several examples showing the limitations of field and laboratory data.

Assume we have surveyed the presence and abundance of fish species in a stream above and below the discharge of runoff from a waste site and that we find fewer species and numbers of fish below the discharge

point. How do we know these differences are outside the range of natural variation and not due to chance? Ecological systems vary considerably from site to site and from time to time. Barring the case of an almost total absence of fish below the waste site, a single upstream site is normally an insufficient reference for establishing the range of natural variation. While it is ordinarily very easy to measure ecological change, it is not at all easy to determine if the measured change is outside the range of normal variation.

Furthermore, natural populations are influenced by a wide range of natural and anthropogenic stressors. Even if we assume the upstream and downstream differences are outside the range of normal variation, how do we know they are caused by the waste site? Large population differences are often caused by habitat changes, presence or absence of predators, diseases, and other poorly understood factors. Even though we know a change is out of the ordinary, we cannot assume that a physically co-located pollutant or activity is causing the stress.

Limitations also exist for interpreting laboratory data. Suppose we take a soil sample from a waste site, and in the laboratory we measure its toxicity to earthworms, finding that it kills 20% of the animals tested. What does this mean in terms of the population of worms on site? Such a population normally experiences a high mortality rate from predators, drought, winterkill, etc. However, the population can sustain its numbers over time by mechanisms which compensate for mortality. There are circumstances where this

additional toxic stress would not be noticed within the natural dynamics of the worm population. On the other hand, there could be circumstances when this 20% mortality rate measured in the lab could be magnified in the field to much greater mortality rate, even to the point of extirpation. This is just one illustration why it is not possible to make straightforward or simple extrapolations with great confidence from one level of ecological organization to another.

We have a rich history of methods for gathering data and improving our understanding of ecological systems. However, we have very few examples, especially for waste sites, where this data has been used to draw rigorous ecological conclusions. This doesn't mean that it can't be done, but that it will require careful design at the inception of an ecological assessment and more blending of different types of biological and ecological information than we've been accustomed to in the past.

It is the thesis of this paper that we have the concepts and methods to conduct useful ecological assessments, but that we have not been using our concepts and methods in the most effective manner. Further, the most important improvement we can make is to move away from our tendency first to measure the things we know how to measure and then try to draw conclusions. To draw useful ecological conclusions, we must define our assessment questions at the outset and then gather the data to answer those questions.

LEVELS OF BIOLOGICAL/ECOLOGICAL ORGANIZATION

For clarity we will define the key terms used in this paper. By "ecological assessment" we mean some quantitative evaluation of adverse change in a population, community or ecosystem at a specific location, such as a waste site; and the identification of the probable cause or causes of this change. The term "ecological" refers to the interactions among organisms and their environments. To clarify this, we need to describe the different levels of biological/ ecological organization.

Individual

A basic biological unit is the individual organism. It is often very useful to determine how a representative individual plant or animal responds to a stress. This is the usual endpoint of toxicological analysis and essentially the counterpart of human health assessment. Normally, we test the effect of a chemical on a group of fish in a tank, to determine the probable response of a typical individual fish. Drawing from the experience with human health assessment, we are very accomplished at measuring stress at the level of the individual organism. However, from this information alone, one cannot, other than by gross inference, draw ecological conclusions.

Population

Ecologically and evolutionarily, the value of an individual is its contribution to a population of which it is a transient member. It is at the population level that much of nature's adaptation to natural environmental stress occurs. This natural stress is considerable. Populations are very dynamic, being influenced by a wide range of stresses such as predation, loss of habitat, climate fluctuations, disease, and starvation. One cannot simply translate an effect of a stress such as a toxicant on an individual organism to a comparable effect at the population level. From experience, we know that the population response can be substantially greater or less. For a number of species, we have the capability for measuring and, to some extent, predicting the level of natural populations. However, this cannot be done with the precision or sophistication with which we can assess effects at the level of the individual organism.

Community

Populations of species interact with other species in the natural environment. Sometimes these interspecies linkages are tight, such as for the panda which eats only the bamboo plant. In other cases, linkages are weak, such as for an opossum which subsists on many types of foods in a variety of environments. Natural groupings of interacting species we call communities. Socially, we tend to place great value on certain communities, such as certain forest communities. Despite extensive efforts to develop simple indices of community structure, we are not generally capable of effectively characterizing

what we mean by a community, especially in terms necessary for assessment. There are however, some recent advances in this area that offer promise (Karr, 1986).

Ecosystem

A biological community plus its nonliving environment is what we call an ecosystem. Examples would be a lake, a wetland, or a forest, including soil, air and water, as well as living components. There are no distinct boundaries for ecosystems. They tend to overlap and vary enormously in scale according to the question being asked. An ecosystem could be a single rotting log in a forest or the entire earth. We normally describe ecosystems in terms of their functions. How much timber will a forest produce? How much pollutant will a wetland remove? How much carbon dioxide will an Amazonian jungle consume? Socially and scientifically, we express great concern for ecosystems. However, our assessment capability at this level is very limited (Schindler, 1987).

Clearly ecological systems are very complex, operating at many different levels and scales. Also they are highly variable. They are constantly changing, both in response to natural environmental change and to natural ecological succession. Does this complexity and variability mean that useful ecological assessments exceed our grasp? We think not. Certainly there are many questions we'll not be able to answer. However, with the right approach and degree of rigor, we

believe that we now have the capability for answering many useful waste site ecological assessment questions.

PURPOSE OF AN ASSESSMENT

Within the current state of ecological knowledge, there appear to be four useful questions that can be answered for many sites:

1. What adverse ecological change has occurred, on-site and off-site?

2. What adverse change can be attributed to waste site contaminants or other site activities?

3. What is the extent and severity of adverse change?

4. What adverse change has the potential for abatement as a result of cleanup?

THE ECOLOGICAL ASSESSMENT END POINT

Critical to all four of these questions is the definition of "adverse change." As discussed above, many measured ecological changes are not adverse; they may be within the range of natural variation. Moreover, what may be "adverse" at the level of biological organization we can conveniently measure; i.e., the individual, may not be adverse at the level of our ecological interest; i.e., the

population or community. Therefore, the most important single step in an assessment is defining what ecological entity or attribute we wish to assess. This we will call the ecological "assessment endpoint." The assessment endpoint is that feature in the environment for which we consider a change to be undesirable. An assessment may have a single endpoint or more commonly, several endpoints. An assessment endpoint, in addition to being something we value, must be something we are capable of quantitatively assessing. Either we must be able to measure the endpoint directly, or to measure something else, from which we can estimate quantitatively the endpoint. (This definition is similar, but not identical to one developed by Suter, 1989.)

For humans, the health of the individual is normally the assessment endpoint. In ecological systems, the individual is much less important. Generally, our concern is for the population of a species of interest, such as Canadian geese; the composition of a biological community, such as the set of aquatic biota needed to sustain a trout fishery; or the functioning of an ecosystem, such as clam yield in an estuary. In the few cases where we use an individual organism as an assessment endpoint, such as a member of endangered species, we assume each individual is critical for the population and the preservation of the species.

It is desirable whenever possible, to select an endpoint based on its intrinsic value. At the population level this is often possible: an endangered or threatened species (e.g. the peregrine falcon), a

commercially important species (e.g. the razor clam), a recreationally important species (e.g. rainbow trout), an aesthetically important species (e.g. whistling swan), a culturally important species (e.g. the bald eagle). At the community level most intrinsically valued attributes tend to be expressed in terms of a particular species and the set of other species necessary for its sustenance. At the ecosystem level one defines functional attributes such as timber yield for a forested ecosystem, or crop yield for an agricultural system.

Intrinsically valued endpoints are the most useful and effective kind for assessments. They tend to have the highest degree of precision and understandability for assessment. However, we are not able in many cases to define intrinsically valued endpoints. In addition to specific intrinsic ecological attributes, we also socially value the protection of ecological systems. Presumably this is based on the assumption that we don't understand ecological systems well enough to identify all of their important attributes and that we are concerned that ecological systems may have a future value that we don't currently recognize. Therefore, we also use "protective" assessment endpoints. These take the form of questions such as:

- Is there change outside the range of natural variation for that type of ecological system?

- What level of stress (e.g. toxicity) is present that has the potential for causing biological harm?

These "protective" endpoints have a long and useful history. They are the basis for chemical Water Quality Criteria, as well as regulations for natural resource damage assessment at superfund sites (US Dept Interior, 1987). Many ecological field surveys are designed around protective endpoints to compare differences between a site of concern and some presumably undisturbed reference site.

On the surface protective endpoints are very attractive. When expressed as "no change" or "no stress" they imply a level of absoluteness that is reassuring. However, these types of endpoints have serious limitations that have recently become very evident. Natural reference conditions are very difficult to define, because of statistical difficulties and natural ecological systems have been so altered that systems unperturbed by modern human influences no longer exist. In practice "no change" or "no stress" are relative rather than absolute concepts. With sufficient effort some change or contamination can always be measured; thus one must always decide how much change or what degree of contamination is acceptable. While we will continue to use protective endpoints, we must be very careful to be explicit about their limitations, and not to use them to draw ecological conclusions beyond these limits.

ASSESSMENT APPROACHES

There are three general sources of data used for ecological assess-

ment of waste sites:

- o field surveys measure the distribution and abundance of taxonomic groups of organisms, and some functional attributes of ecological systems.
- o bioassays measure a direct toxic response in the field or in the laboratory
- o biomarkers indicate exposure to specific chemicals or classes of chemicals.

FIELD SURVEYS

Generally field surveys are essential for selecting the appropriate ecological assessment endpoints for a site. Also, they are the only way that actual ecological effects can be demonstrated. Sampling designs and protocols for determination of populations of plants, animals, and microbes have been the subject of ecology from its inception. Although no rigid guidelines for sampling are accepted universally, the concepts of adequacy of sample, objectivity, and precision are well entrenched in all field oriented studies. Protocols can be modified to match the peculiarities of the site and the objectives of the sampling effort.

Field surveys may be restricted at hazardous waste sites because of problems of access and risk to workers. At some sites surveys may not be appropriate because of their limited size. However, in a large number of sites, field surveys can play a major role.

Conventional on-site surveys of vegetation and animal populations can generate patterns of distribution and abundance of the taxonomic groups. Given the time available for data collection at many hazardous waste sites, it is crucial to recognize the large error margins in most survey data. One-time sampling efforts almost always under estimate species richness. Ephemeral populations are easily missed. Quantitative estimates from one-time sampling efforts are static and thus miss the dynamics of the site. There are distinct limitations to the ecological conclusions we can draw from changes in population numbers. Nevertheless, indispensable information can be acquired from field sampling, in some cases even through rather cursory reconnaissance.

In addition to traditional methods of direct censusing of of biota, remote sensing can be very useful for field surveys. Vegetation structure and, to some extent, composition can be determined remotely utilizing conventional aerial photography and infrared photography, or more sophisticated radiometric signals that permit analysis of spatial and temporal changes at and surrounding the site. More importantly, because toxicants can alter spectral reflectance patterns of vegetation, infra-red photography and radiometric sensors (Duinker and Nilsson, 1988) show great promise for use in defining the spatial boundaries of impact.

Table 1 summarizes the capabilities and limitations of field surveys. For more detailed discussion see Kapustka et al. (1988).

Table 1. Capabilities and limitations of field surveys (Adapted from Baker 1988.)

Capabilities	Limitations
+ necessary to define endpoints of relevance	- restricted to correlation analysis, does not establish causation
+ most direct way to demonstrate adverse change	- legal and safety concerns restrict access
+ large selection of available sampling techniques permit measurement to specified accuracy	- large natural variability may mask significant effects
+ reflect the biological integration of all stresses	- detailed sampling can be expensive
+ amenable to sophisticated remote sensing technology (at least major vegetation components)	- "snapshot" view misses time dynamics

BIOASSAYS

Bioassays have traditionally been used to determine the effect of a single chemical on an organism under controlled conditions. Laboratory bioassay conditions cannot replicate the natural environment, in terms of chemical exposure, simultaneous environmental stresses or other ecological conditions. Used in the laboratory, bioassays are essentially an instrument, producing a measured biological response that varies depending upon how the instrument is used.

Results have an uncertain relationship with field ecological responses.

Nontheless, bioassays have been extremely useful for comparing toxicity of chemicals and determining a range of response in different types of organisms. In some cases chronic bioassays have been used to establish what appear to be effective levels of protection for contaminants in aquatic systems (Sloof, 1985). However, experience has shown that bioassays can result in both false negative and false positive findings.

More recently, bioassays have been employed to evaluate toxicity of environmental samples such as waste water effluents or elutates from waste site soils. In this way, they are able to integrate the response of an organism to simultaneous exposure from multiple differentially toxic agents.

One feature of bioassays is especially important for waste site assessment. Usually they are the only way to experimentally establish a causal relationship between a contaminant and an observed effect. Field surveys can only establish correlations between effects and presumed causes. Bioassays provide strong evidence for causation.

However close the laboratory can be made to similate field conditions, bioassays remain a surrogate measure of ecological effects. In

addition, laboratory bioassays will always be limited to organisms which can be cultured. Cognizant of such limitations, efforts continue toward developing a broader array of bioassay organisms and toward adapting existing bioassay procedures so that the test may be performed in situ. Successful examples of in situ terrestrial bioassays to date include detecting and monitoring environmental contamination utilizing honey bees (Bromenshenck, 1985, 1988), earthworm bioassays (Callahan and Menzie, personal communication, Menzie, et al., 1988). In the near term, it will often be helpful to use a combination of laboratory and in situ assays. This duplicity is needed in order to provide appropriate calibration of laboratory and in situ measurements. In part this is because of the large data base already assembled with laboratory bioassays.

In depth discussions of protocols for specific bioassays and data analyses/interpretations may be found in Greene et al., (1988) and Weber et al., (1988).

Table 2. Capabilities and limitations of bioassays (Adapted from Baker, 1988.)

Capabilities

+ can help establish causality
+ extensive laboratory data base and selection of bioassays
+ can integrate multiple, simultaneous chemical stresses
+ can reflect bioavailability
+ test conditions can be manipulated or adapted to meet different specification (including adaptation to in situ conditions)
+ chronic assays can more closely mimic field response and actual field exposures

Limitations

- assay conditions (especially in the laboratory) are artificial in terms of exposure and other environmental stresses
- restricted to culturable organisms
- results cannot be directly translated into population effects in the field
- results depend upon specific techniques and test conditions

BIOMARKERS

Biomarkers are measures of molecular and/or physiological features of organisms which are used to reveal a sublethal (often subtle)

response to some stressor. A given biomarker response may be ephemeral or sustained; it may be specifically linked to a chemical or it may be associated with a general class of stressors. The biomarker response in most cases is measured in an individual and provides evidence that the individual in question has experienced exposure to the stress. Although this subdiscipline of environmental biology is in its infancy, already excellent tools exist; some with clearly defined relationships between what is measured and the assessment endpoint. DiGuillio (1988) discusses the applicability of biomarkers and presents selected case studies relevant to waste site assessment.

Several key virtues of biomarkers are flexibility for use in the lab or in the field as well as on cultured or wild organisms. In this way, biomarkers can aid in defining relationships between laboratory and in situ bioassays as well as relationships between bioassay organisms and the larger array of wild organisms.

Table 3. Capabilities and limitations of biomarkers. (Adapted from Baker, 1988.)

Capabilities

+ evidence of exposure to sublethal concentrations of stressers
+ may be diagnostic
+ amenable to both laboratory and field conditions
+ very active area of research showing great promise

Limitations

- linkage to ecological effects not inherently clear
- only a few established biomarker systems available
- may be operationally complex

Although several limitations exist to the generalized use of biomarkers exist (e.g. technical uncertainties regarding the sensitivity, interference, general applicability across taxonomic lines), some have been used very effectively to demonstrate adverse effects on organisms due to contaminants. Examples include cholinesterase depression (Hill & Fleming, 1982), mutation frequency in plants (Lower, 1983), karyotype analysis (McBee, 1987), flow cytometry to measure cellular DNA content (McBee, 1987), DNA unwinding (Shugart 1988a,b), and analysis of genetic diversity of populations via measurement of allelic distributions of metabolic enzymes (Facemire, et al., 1988; Gillespie and Guttman, 1988; Kopp, et al., 1988). In all likelihood as more studies are completed, and as new biomarkers are perfected for field measurements, the theoretical framework to linking biomarker measurements to ecological endpoints will come into sharper focus.

Each of these sources of data has different capabilities and limitations. There is often a tendency to rely too heavily on one source to the exclusion of others -- toxicologists arguing for one approach, field biologists for another. In most cases, it is only by combining the strengths of these various data sources into a "weight

of evidence" approach that we can effectively bring the power of ecological science to bear on assessment decisions.

CONCLUSIONS

Waste site ecological assessment is still in its formative stages. However, there appear to be no major obstacles preventing it from rapidly developing into a vigorous and useful science. There is no simple or single approach that will be generally applicable. Given the complexity of ecological systems, one must design each assessment carefully using the methods appropriate for the questions being asked. We suggest several guidelines.

1. To determine how organisms are responding in the real world, one must assess at an ecological level of response--the population or above.
2. Careful definition of assessment endpoints at the outset is critical for a useful and scientifically defensible assessment.
   - intrinsically-valued endpoints are best, if they can be defined and assessed.
   - if protective endpoints are used, their limitations must be recognized.
3. Each of the different types of biological and ecological information used for assessments has limitations. In most cases it is best to use of blend of information from toxicity tests, biomarkers and field surveys.

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